Climate Change and Food Security in Nigeria: Implications for Staple Crop Production

Abstract

This study contributes to the literature on environmental economics and sustainability by examining the implications of climate change on staple food production. The specific objectives centre on investigating how carbon dioxide emissions, rainfall, temperature and methane emissions affect crop production in Nigeria between 1990 and 2023. Time series data were obtained from the CBN Statistical Bulletin, World Bank and FAO statistics. Descriptive statistics and econometric techniques of unit root, cointegration and least squares estimation were applied for the data analysis. The ADF unit root test results showed that the variables are mixed integrated with carbon dioxide emissions being integrated of order zero while the other variables are integrated of order one. The bounds cointegration test results showed that food production has a long-run relationship with carbon dioxide emissions, rainfall, temperature and methane emissions. The findings showed that carbon dioxide emission positively and significantly affects food production in the long and short run. This finding indicates that carbon dioxide emission does not adversely affect the production of food crops. Similarly, the results showed that average rainfall affected food production positively in the long and short run. This finding is significant at the 5% level, indicating that variability in rainfall is not detrimental to food production during the study period. The effect of average temperature on food production is negative in the long run. Although this finding is not significant at the 5% level, it suggests that variability in the climatic conditions poses a threat to food production in Nigeria. The results also showed that methane emissions contributed positively to food production. This highlights that methane emissions increase with the increase in food production. Given the findings, the study recommends among others that policymakers should ensure strict adherence to environmental laws and promote adaptation strategies to minimize the extent temperature variability undermines the growth of food production in Nigeria.

Keywords: *Climate change, staple food, crop production, carbon dioxide emissions, rainfall, temperature and methane emissions*

1. Introduction

The implications of climate change on food security have continued to attract the attention of policymakers, researchers and development agencies. This followed the understanding that exerts numerous impacts on global agricultural production, trade patterns, food security, and rural livelihoods. Olawuni (2022) posits that the complex relationship between climate change and staple food production poses challenges and opportunities for countries, farmers, marketers, consumers, and policymakers. It is also argued that the changing dimensions of climate change have threatened climate-sensitive sectors, such as agriculture with attendant implications on food security. According to Adeosun, Asare-Nuamah & Mabe(2023), climate change tends to exacerbate the vulnerability of agricultural output growth by altering temperature, precipitation patterns and water availability, among others. Following considerable climatic and topographic variability, Africa, especially the East African region tends to witness spatial and temporal variation in the response of different crops to climate change (Thornton*et al.*, 2010).

As Nigeria grapples with rising temperatures, erratic rainfall patterns, and increased frequency of extreme weather events, the agricultural sector faces unprecedented challenges. This followed the understanding that staple crops such as rice, maize, and cassava are central to the Nigerianeconomy, thus making their vulnerability to climate change a critical concern.It is arguedthat developing economies including Nigeria are at risk of adverse effects of climate change considering the prevalent high level of temperature, poor adaptation capacity, absence of early warning and poor income of farmers. It is pertinent to note that Nigeria has experienced frequent environmental disasters which worsens the country's vulnerabilityto changing climatic conditions. For instance, Ogbuchi (2020) posits that Nigeria has experienced severe flooding in recent times with huge associated agricultural losses including crops and livestock. Other studies (Ani, Anyika& Mutambara, 2021; Ojo & Baiyegunhi,2021)argue that extreme climatic conditions including desertification, high rainfall, drought and flooding have continued to worsen the food security crisis in Nigeria.

Given that Nigeria's agriculture is predominantly rain-fed, it is particularly vulnerable to the impacts of climate change, including temperature rise, erratic rainfall patterns, droughts, floods, and extreme weather events. These climate-related challenges tend to undermine staple food production and exacerbate food insecurity while hinderingthe country's economic development process. Drawing from the foregoing,this study seeks to deepen the understanding of the implications of climate change on staple food production. Following the introduction in Section 1, the rest of this paper is organised as follows: Section 2 provides the review of related literature. Sections 3 and 4 embody the methodology and results respectively whereas Section 5 concludes the paper.

2. Literature Review

2.1 Theoretical Literature

The crop growth model was developed by De Wit and Goudriaan (1978) to explain the effects of climate change on crop yield. It is predicated on the idea that weather variations are significant factors that influence agricultural productivity. This is due to the idea that regional differences exist in environmental circumstances. Notably, climate change is believed to pose a significant threat to agriculture, affecting crop yields, food security, and farming practices.As documented in the extant literature,the crop growth model provides the basis for understanding these impacts, simulating crop responses to various climatic conditions, and guiding adaptation strategies. According to Wheeler and Tiffin (2009), one method used in the economic literature on climate change that offers a foundation for understanding the implications of climate change on agricultural output is the crop growth model. The popularity of this model has increased its application among researchers.

Theoretically, it is believed that the link between climate change and crop yield is adequately captured by the crop yield model (Sands and Edmonds, 2005). Thus, the model offers a straightforward approach to the assessment of the implications of weather changes on agriculture.Consequently, climate change and weather variability are identified as important sources of crop yield changes. The understanding of how different crops respond to climate variables is enhanced by the crop growth model which helpsresearchers to identify which crops are most vulnerable to climate change and guides farmers and policymakers to select appropriate adaptation strategies.In sum, the crop growth model has been described as imperative to understanding the complex interactions between climate change and agriculture output including staple food production given that it provides valuable insights that can guide adaptation, inform policy, and enhance food security.

2.2 Stylized Facts on Food Production

Food production in Nigeria has varied in the past two decades in response to temperature, rainfall, changing weather events and other environmental factors. The trends of the series between 2010 and 2023 are reported in Figure 1.

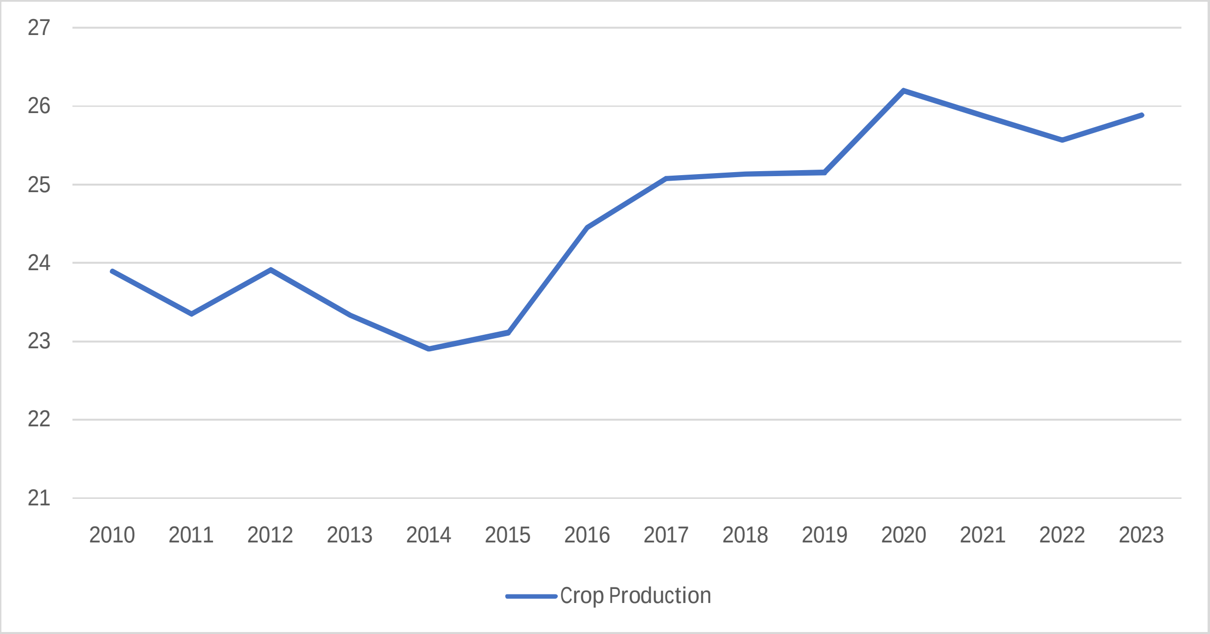

Fig1: Time series trends of crop production in Nigeria, 2010-2023

Source: Researchers' illustration based on data from the CBN Statistical Bulletin (2023)

As observed in Figure 1, crop production fluctuated during the sample period. It decreased marginally from 23.89% in 2010 to 23.35% in 2011 before increasing to 23.91% in 2012. Crop production reached an all-time low value of 22.9% in 2014. This could be attributed to the perceived risk in the wake of the 2015 general elections. In addition, the graph showed that crop production increased to 24.44% and 25.08% in 2016 and 2017, respectively. It further increased to a record-highlevel of 26.21% in 2020 before declining to 25.57% and 25.88% in 2022 and 2023, respectively. The variations in crop production could be attributed to the changing climatic conditions and macroeconomic environment, among other factors. It further explains the growing challenges of food insecurity faced in Nigeria as crop production accounts for a significant amount of staple food available to households in Nigeria.

2.3 Empirical Literature

The implication of climate change on staple food production has been the subject of extensive empirical research. These studies are mainly predicated on crop growth models with varying findings across countries and regions. For instance, Albert and Agala (2023) employed a correlational research design to explore the relationship between climate change and agricultural production in Bayelsa State, Nigeria. The population of this study comprised 3399 farmers in the state with a sample size of 359 respondents. The findings showed that climate changeinfluences crop production in Bayelsa State by 74%. Similarly, the results showed that climate change significantly affected livestock production in Bayelsa State. Given the findings, the study recommended among others that policymakers should adopt proactive and innovative approaches through the involvement of key stakeholders to substantially address the challenges of climate change on crop and livestock production.

Galindo, Reyes and Alatorre (2015) employed the Ricardian model in analyzing the potential impacts of climate on agriculture in Mexico using panel data. The study covered 2,431 municipalities between 2003 and 2009, distinguishing between irrigated, rainfed and mixed farms. The findings reveal that the vulnerability of the irrigated farms manifests more during temperature changes. However, rainfed farms are more vulnerable to changes in precipitation and extreme weather outcomes. It was specifically uncovered from the findings that rise in temperature and precipitation by 2.5^0C and 10% respectively causes between -18.6 and -36.4 percent losses in net revenue.

In a related study, Eneji*et al.*(2020) investigated the impact of climate change on agriculture and food security in Nigeria between1998 and 2018. The study adopted secondary data and the Ordinary Least Square (OLS) technique, involving a multiple regression model to analyze the causal relationship of climate change on food production and food security. The study employed annual time series data sourced from the CBN. Statistical Bulletin. The findings from the regression analysis showed that there is a negative effect of average rainfall and carbon dioxide emissions on agricultureoutput. This highlights that climate change is detrimental to food security. Based on the findings, this study recommends that the government should take proactive steps in addressing environmental problems which undermine the goal of food security in Nigeria.

Focusing on temperature and precipitation, Pickson et al. (2023) estimated the actual trends in climate change variables across 12 Asian countries between 1970 and 2018 and examined their implications on food production. The findings showed that annual temperature across Asian regions trends positively. The geographical findings show that, with the exception of South-Eastern Asia, where the effect is minimal, temperature considerably influences food production in all regions. In Western, South-Eastern, and Southern Asia, rainfall positively affected food production, but the effect is negative in Eastern Asia. The results also demonstrate that the effects of climatic factors on food production vary greatly across countries. The study recommended that Asia requires significant investments in research initiatives, agricultural extension, and better irrigation systems.

Using a using panel data from 31 Chinese provinces and cities, Lee, Zeng & Luo (2024) investigated how climate change contributed to food security between 1994 and 2020. The findings revealed that climate change significantly affects food security. The results further showed that regional heterogeneity exists, with climate change having significant moderating effects on food security in non-food-producing regions and rainfall having significant effects in north and central regions. Thus, the study recommended strengthening climate change resilience. Similarly, Adesete, Olanubi & Dauda(2023) explored the link between climate change and food security in the Sub-Saharan African Region (SSA) with a focus on 30 countries within the region. The findings from the system generalized method of moments (GMM) model showed that greenhouse gas emissionsexacerbated the malnourishment rate which undermined the goal of food security in SSA. In addition, climate change and food price have a negative significant effect on food security, while income and food supply have a positive significant impact on food security in SSA. Given the findings, the study recommended that the countries in the study region should prioritise the goal of zero net emissions.

Bedasa & Bedemo(2023)applied a GMM estimator of the dynamic panel model toanalyse the effects of climate change on food insecurity in the Horn of Africa. The study findings show that food insecurity in the Horn of Africa is adversely affected by temperature. The results further showed that a 1% increase in precipitation resulted in a 0.023% decrease in food insecurity. The study results indicate that cereal yield, food production index, and political stability were significant and negatively influenced food insecurity. This study concluded that climate change results in food insecurity in the Horn of Africa, and food availability is expected to be reduced in the region. Based on the findings, the study recommended that policymakers should adopt high-temperature and drought-resistant varieties of improved food crops to foster food security.

3. Methodology

3.1 Research Design

Ex-post facto research design also known as quasi-experimental research design was adopted for this study. This is considered ideal for this given that it allows for analysing existing data or events to draw inferences about possible causes or effects without manipulating the datasets. Shadish, Cook & Campbell (2002) posit that ex-post facto research design has the potential to offer valuable insights into associations and patterns in real-world settings.

3.2 Nature and Sources of Data

Annual time series data for each of the variables were used for this study. The datasets were obtained from notable sources includingthe Central Bank of Nigeria Statistical Bulletin, Food and Agriculture Organization (FAO) Statistics and World Bank World Development Indicators (WDI).

3.3Model Specification

The model set up for this study closely followed the work ofOpeyemi, Husseini & Ikumapayi (2022),Amaefule *et al.* (2023) andLee, Zeng & Luo (2024) with some modifications in terms of improvements in the measure of climate change indicators. The functional form of the model is specified as follows:

$FOP = f(CO_2, \text{ARF, ATP, MTE})$ (1)

FOP = Food production (measure by crop product),CO_2 = Carbon emission, *ARF*= Annual rainfall, *ATP* = Annual temperature**,** *MTE* = Total Methane emission

The model for this study is built upon the autoregressive distributed lag (ARDL) model and the generalized ARDL model is specified as follows:

$$\Delta y_t = \alpha_0 + \Phi y_{t-1} + \boldsymbol{\beta}'\mathrm{X}_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta y_{t-i} + \sum_{j=0}^{q-1} \boldsymbol{\lambda}'_j \Delta \mathrm{X}_{t-j} + \varepsilon_t \quad (2)$$

Where: Y_t= dependent variable, Y_{t-1} = lagged dependent variable, X_t= vector of regressor, X_{t-1} = vector of lagged dependent regressor, Φ and β = long-run multipliers, *y* and λ = short-run parameters, p = optimal lag of the dependent variable, q = optimal lag of the regressor, Δ= first difference operator and *E* = error term

Specifically, the ARDL model for this study based on the variables' notations in equations (1) is provided below:

$$\Delta FOP_{t=} \quad \alpha_0 \quad + \quad \sum_{i=1}^{p} \alpha_1 \Delta FOP_{t-1} + \sum_{i=1}^{q} \alpha_2 \Delta C02_{t-1} + \sum_{i=1}^{q} \alpha_3 \Delta ARF_{t-1} + \sum_{i=1}^{q} \alpha_4 \Delta ATP_{t-1} + \sum_{i=1}^{q} \alpha_5 \Delta MTE_{t-1} + \lambda_1 FOP_{t-1} + \lambda_2 C02_{t-1} + \lambda_3 ARF_{t-1} + \lambda_4 ATP_{t-1} + \lambda_5 MTE_{t-1} + \varepsilon_t \quad (3)$$

Where: α_0 = constant parameter to be estimated, $\alpha_1 - \alpha_5$ = short run parameters,λ_1 - λ_5 = long-run multipliers, p = optimal lag for each of the dependent variables, q = optimal lag of the independent variables, Δ= first difference operator and ε_t= White noise error term

3.4 Method of Data Analysis

Theaugmented Dickey-Fuller (ADF) method credited toDickey & Fuller (1981) was employed to test the null hypothesis of unit root (nonstationary) against the alternative hypothesis of no unit root (stationary) in each of the variables at the 5% level. The model for the ADF unit root test is specified

$$\Delta Y_t = \propto_0 + \propto_1 Y_{t-1} + \sum_{i=1}^{m} \beta_i \Delta Y_{t-i} + \lambda_t \quad (4)$$

Where: Y_t = variables in the model, $\propto_1$ and β_i = parameter estimates, m = lag length, Δ= First difference operator and λ_t = Random disturbance term

The cointegration test focused on the bound test developed byPesaran& Shin (1999) and applied by Pesaran, Shin& Smith(2001). This cointegration method was adopted following the evidence of mixed integration in the series. More importantly, the least squares method was applied to estimate the ARDL model to ascertain the short- and long-run effects of climate change indicators on crop production. When compared to alternative estimating methods, the ARDL methodology has several desirable statistical advantages. First, the ARDL method allows for estimating both the static and dynamic impacts of the independent variables on the dependent variable. It is also considered appropriate for relatively small samples and series with evidence of mixed order of integration[I(0) and I(1)]. Kripfganz & Schneider (2018) posit that the ARDL model has been widely utilised in single-equation time series setups.However, one of the potential limitations of the ARDL is that the model tends to yield biased or inconsistent estimates if the assumption of linear relationship between variables is not fulfilled.Post-estimation diagnostics tests such as serial correlation, heteroscedasticity and regression specification shall be applied in this study. Essentially, the Breusch-Godfrey method was applied for the serial correlation while White's (1980) method formed the basis for the heteroscedasticity test.

4. Results and Discussion

4.1 Unit Root Test

As previously noted, the unit root test for this study was based on the ADF method. The results are presented in Table 1.

Table 1: Summary of unit root test results

Variable	ADF Statistics at levels	ADF Statistics at 1st difference	5% Critical value	Order of integration
FOP	-1.6144	-5.935-	-2.95	I(1)
CO2	-3.431716	-	-2.95	I(0)
ARF	-1.762	-5.606	-2.95	I(1)
ATP	-1.280	-6.728	-2.95	I(1)
MTE	-1.455	-4.925	-2.95	I(1)

Source: E-views output (2024)

The ADF unit root test results forcrop production, carbon emission, annual rainfall, annual temperature, and methane emission showed that all the variables are not stationary at levels except CO2. This is because the estimated ADF statistics for crop production, annual rainfall, averagetemperature, and methane emission at levels are less than the corresponding critical value in absolute termsat the 5% percentage significance level. Therefore, we cannot reject the null hypothesis that these variables(crop production, annual rainfall, averagetemperature, and methane emission) have unit roots. Consequently, the variables were subjected to first difference and the results showed that they became stationary at first difference given that their ADF statistics are greater than their critical value in absolute terms at the 5% significance level. This finding indicates that these variables are integrated of order one, I(1). However, carbon emission is stationary at levels given that the ADF statistics is greater than the corresponding critical value at the 5% level in absolute terms. Hence, CO2 is integrated of order zero, I(0). In sum, the unit root test results showed that the variables are mixed integrated.

4.2 Cointegration Test

The results of the bounds cointegration test are presented in Table 2.

Table 2: Bounds cointegration test results

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	7.537	10%	2.2	3.09

K	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Source: E-views output (2024)

The result shows that the computed F-statistic (7.537) is greater than the upper bound critical value (3.49) at the 5% significance level. This finding necessitates the rejection of the null hypothesis that no long-run relationship exists among the variables. Consequently, a long-run relationship exists between crop production and climate change, indicating that climate changecan be relied upon in predicting changes in crop production. The evidence of cointegration among the variables corroborates the findings of Idumah*et al.* (2016), Abbas, Kousar & Khan (2022) and Ceesay& Ndiaye(2022) who reported that climate change is a long-term relationship with food production in developing economies.

4.3 Model Estimation

The least squares estimation method was applied to analyse the effects of climate change on staple food production. The long and short results of the ARDL model are presented in Table 3.

Table 3: Summary of the ARDL results

Dependent Variable: FOP				
Short run results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2)	20.422881	5.005514	4.080077	0.0005
D(ARF)	0.047905	0.021282	2.250955	0.0352
D(ATP)	0.573491	0.614947	0.932586	0.3616
D(MTE)	0.125401	0.054859	2.285889	0.0328
D(MTE(-1))	0.068716	0.075584	0.909136	0.3736
CointEq(-1)	-0.672189	0.122014	-5.509118	0.0000
Long run results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2	30.382653	8.837637	3.437871	0.0025
ARF	0.071268	0.032206	2.212859	0.0381
ATP	-0.786058	1.395804	-0.563158	0.5793
MTE	0.360631	0.051927	6.945020	0.0000
C	16.939502	35.549431	0.476506	0.6386
Adjusted R-squared	0.926982		Prob(F-stat.)	0.0000

Source: E-views output (2024)

The results showed that carbon dioxide emissions contributed positively to food production during the study period. This finding is contrary to the a priori expectations, indicating that changes in carbon dioxide emissions do not undermine the growth of food production. The positive effect of carbon dioxide emissions on food production corroborates the findings of Appiah, Du & Poku. (2018) and Ejemeyovwi, Obindah & Doyah (2018) reported that there exists a positive relationship between agriculture output and carbon dioxide emissions. This is contrary to the findings of Opeyemi, Husseini & Ikumapayi (2022) and Amaefule *et al.* (2023) who found that climate change in the form of carbon dioxide emissions adversely affected agriculture output. The results further showed that average rainfall affected food production positive during the study period. This finding highlights the dependence of food production on natural environmental resources, especially rainfall. In comparison, this finding is consistent with the results of Idumah *et al.* (2016) and Gershon & Mbajekwe (2020) who reported that annual rainfall contributed significantly to the growth of food production.

In addition, the results showed that the effect of average temperature on food production is negative, indicating that an increase in temperature is associated with a decrease in food production. This finding authenticates the previous results by Olufemi, Joshua & Abraham-Salamatu (2020) and Onyeneke *et al.* (2024) who reported the dampening effect of temperature variability of the crop yield. This finding implies that food production during the study period is vulnerable to climate variability with increasing maximum temperature. The results further showed that methane emissions positively affected food production during the study period. This finding could be attributed to the fact that most methane emissions are associated with agriculture activities. Thus, agriculture yield including food production tends to be associated with an increase in methane emissions. This finding aligns with the results of Ogbowuokara *et al.* (2023) who reported that food production increases with an increase in methane emissions. The error correction coefficient (-0.67218) showed that reversion to a long-run equilibrium position is achieved at a speed of 67.22%. This finding indicates that the model can speedily adjust to a long-run position in less than one and a half years. The adjusted R-squared (0.9269) showed that about 92.69% of the total variations in food production are jointly explained by the climate change indicators. The probability value (0.0000) of the F-statistic is less than 0.05, indicating that the underlying climate change indicators are significant in explaining changes in food production. This highlights the statistical significance of the estimated ARDL model and the predictive ability of the climatic change indicators in accounting for changes in food production.

Table 4.: Post-estimation test results

Test Type	Test Statistic	Probability value
Breusch-Godfrey Serial Correlation LM Test	0.3655	0.8329
White heteroskedasticity test	15.989	0.0671
Ramsey RESET	1.5703	0.2312

Source: E-views output (2024)

The post-estimation results showed that serial correlation is not an issue for the estimated ARDL at the 5% significance level. This is based on the fact that the Breusch-Godfrey Serial Correlation LM Test's Chi-square statistic's probability value (0.8329) is higher than 0.05. Similarly, the White heteroscedasticity test result indicated that, at the 5% significance level, the probability value (0.0671) of the test statistic is greater than 0.05, indicating that there is no heteroscedasticity issue in the model.The Ramsey RESET results further showed that there is no functional misspecification in the model because the test statistic is associated with a high probability value (0.2312) which is greater than 0.05. The findings provided enough empirical evidence for the reliability of the model for forecast and policy prescription.

5. Conclusion and Recommendations

The variability in climate conditions and the growing concern for food security necessitated the investigation of the effect of climate change on food production. Thus, this study specifically analyzed how changes in carbon dioxide emissions, rainfall, temperatureand methane emissions affect food production in Nigeria. This followed the understanding that changes in weather events and environmental degradation associated with climate change affect the growth of food production in different ways. The findings showed that carbon dioxide emissions and rainfall positively affected food production in the long and short run. This finding indicates that rainfall variability and environmental pollution from carbon dioxide emissions do not adversely affect food production. The results further showed that changes in temperature have a negative effect on food production. This finding attests to the fact that extreme weather events undermine the growth of food production in Nigeria. The results also showed that methane emissions contributed positively to food production. This highlights that methane emissions increase with the increase in food production. Given the findings, this study concludes that climate change in the form of temperature changes has adverse implications on the growth of food production. It is also concluded from the results that the variability of climatic conditions due to carbon dioxide emissions, rainfall and methane emissions are significant predictors of food production in Nigeria. To this end, this study recommends that government should build synergy with other stakeholders in the environment to address the problem of carbon dioxide emissions by controlling industrial and household activities linked to carbon dioxide emissions for sustainable growth in food production. Again, policymakers should prioritise investments in irrigation and multi-purpose dams to address the effects of rainfall variability on food production while ensuring strict adherence to environmental laws and promoting adaptation strategies to minimize the extent temperature variability undermines the growth of food production in Nigeria.

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REFERENCES

1. Abbas, S., Kousar, S., & Khan, M. S. (2022). The role of climate change in food security; empirical evidence over Punjab regions, Pakistan. *Environmental Science and Pollution Research*, *29*(35), 53718-53736.
2. Adeosun, O. T., Asare-Nuamah, P., & Mabe, F. N. (2021). Vulnerability analysis of Nigeria's agricultural output growth and climate change. *Management of Environmental Quality: An International Journal*, *32*(6), 1352-1366.
3. Adesete, A. A., Olanubi, O. E., & Dauda, R. O. (2023). Climate change and food security in selected Sub-Saharan African Countries. *Environment, Development and Sustainability*, *25*(12), 14623-14641.
4. Albert, W. E., & Agala, H. O. (2023). Climate change and agricultural production in bayelsa state, Nigeria. *EPRA International Journal of Climate and Resource Economic Review*, *11*(1), 10-18.

5. Amaefule, C., Shoaga, A., Ebelebe, L. O., & Adeola, A. S. (2023). Carbon emissions, climate change, and Nigeria's agricultural productivity. *European Journal of Sustainable Development Research*, *7*(1), em0206.
6. Ani, K. J., Anyika, V. O., & Mutambara, E. (2021). The impact of climate change on food and human security in Nigeria. *International Journal of Climate Change Strategies and Management*, *14*(2), 148-167.
7. Appiah, K., Du, J., & Poku, J. (2018). Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. *Environmental Science and Pollution Research*, *25*, 24764-24777.
8. Bedasa, Y., & Bedemo, A. (2023). The effect of climate change on food insecurity in the Horn of Africa. *GeoJournal*, *88*(2), 1829-1839.
9. Ceesay, E. K., & Ndiaye, M. B. O. (2022). Climate change, food security and economic growth nexus in the Gambia: Evidence from an econometrics analysis. *Research in Globalization*, *5*, 100089.
10. De Wit, C. T. and Goudriaan, J., 1978, “Simulation of assimilation, respiration and transpiration of crops”, Simulation monograph, PUDOC, Wageningen, The Netherlands
11. Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: journal of the Econometric Society*, 1057-1072.
12. Ejemeyovwi, J., Obindah, G., & Doyah, T. (2018). Carbon dioxide emissions and crop production: Finding a sustainable balance. *International Journal of Energy Economics and Policy*, *8*(4), 303-309.
13. Eneji, M. A., Emmanuel, R. M., Dalut, N. A., &Abdullahi, G. (2020). Impact of climate change on agriculture and food security in Nigeria. *Socialsci Journal*, *6*(1), 41-59.
14. Galindo, L. M., Reyes, O., & Alatorre, J. E. E. (2015). Climate change, irrigation and agricultural activities in Mexico: A Ricardian analysis with panel data. *Journal of Development and Agricultural Economics*, *7*(7), 262-273.
15. Gershon, O., & Mbajekwe, C. (2020). Investigating the nexus of climate change and agricultural production in Nigeria. *International Journal of Energy Economics and Policy*, *10*(6), 1-8.
16. Idumah, F. O., Mangodo, C., Ighodaro, U. B., & Owombo, P. T. (2016). Climate change and food production in Nigeria: implication for food security in Nigeria. *Journal of Agricultural Science*, *8*(2), 74-83.
17. Kripfganz, S., & Schneider, D. C. (2020). Response surface regressions for critical value bounds and approximate p□values in equilibrium correction models 1. *Oxford Bulletin of Economics and Statistics*, *82*(6), 1456-1481.
18. Lee, C. C., Zeng, M., & Luo, K. (2024). How does climate change affect food security? Evidence from China. *Environmental Impact Assessment Review*, *104,* 107324.
19. Ogbowuokara, O. S., Leton, T. G., Ugbebor, J. N., & Orikpete, O. F. (2023). Developing climate governance strategies in Nigeria: An emphasis on methane emissions mitigation. *The Journal of Engineering and Exact Sciences*, *9*(9), 17383-01e.

20. Ogbuchi, T.C. (2020). Quantitative indicators of production of food crops. *Journal of Tropical Agriculture*, 32(1),79-88.
21. Ojo, T. O., & Baiyegunhi, L. J. S. (2021). Climate change perception and its impact on net farm income of smallholder rice farmers in South-West, Nigeria. *Journal of cleaner production*, *310*, 127373.
22. Olawuni, O. (2022). Agricultural financing and agricultural performance in Nigeria. *International Journal of Agricultural Development*, *2*(1), 10-19.
23. Olufemi, O. S., Joshua, M. I., &Salamatu, E. A. (2020). Assessment of temperature variability effect on rice production in Nasarawa State, Nigeria. *International Journal of Environment and Climate Change*, *10(1)*, 91-100.
24. Onyeneke, R. U., Chidiebere-Mark, N. M., & Ayerakwa, H. M. (2024). Impact of Information and Communication Technologies and Renewable Energy Consumption on Carbon Emissions in Africa. *Carbon Research*, *3*(1), 53-71.
25. Opeyemi, G., Husseini, S., & Ikumapayi, H. A. (2022). Climate change and agriculture: Modelling the impact of carbon dioxide emission on cereal yield in Nigeria (1961-2018). *Journal of Research in Forestry, Wildlife and Environment*, *14*(2), 128-134.
26. Pesaran MH, Shin Y (1999) An autoregressive distributed lag modelling approach to cointegration analysis. *In: Strom S (ed) Chapter 11. Econometrics and economic theory in the 20th century: the Ragnar Frisch centennial symposium. Cambridge University Press, Cambridge, pp 371–413.*
27. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289-326.
28. Pickson, R. B., Gui, P., Chen, A., & Boateng, E. (2023). Climate change and food security nexus in Asia: A regional comparison. *Ecological Informatics*, *76*, 102038.
29. Sands, R. D., & Edmonds, J. A. (2005). Climate change impacts for the conterminous USA: an integrated assessment: part 7. Economic analysis of field crops and land use with climate change. *Climatic Change*, *69*(1), 127-150.
30. Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). Quasi-experiments: interrupted time-series designs. *Experimental and quasi-experimental designs for generalized causal inference*, 171-205.
31. Thornton, P. K., Jones, P. G., Alagarswamy, G., Andresen, J., & Herrero, M. (2010). Adapting to climate change: agricultural system and household impacts in East Africa. *Agricultural systems*, *103*(2), 73-82.
32. Wheeler, T., & Tiffin, R. (2009). Costs of adaptation in agriculture, forestry and fisheries. *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates*, 29.